



Revealing the Large Scale Distribution of Star Formation in the Milky Way with WISE

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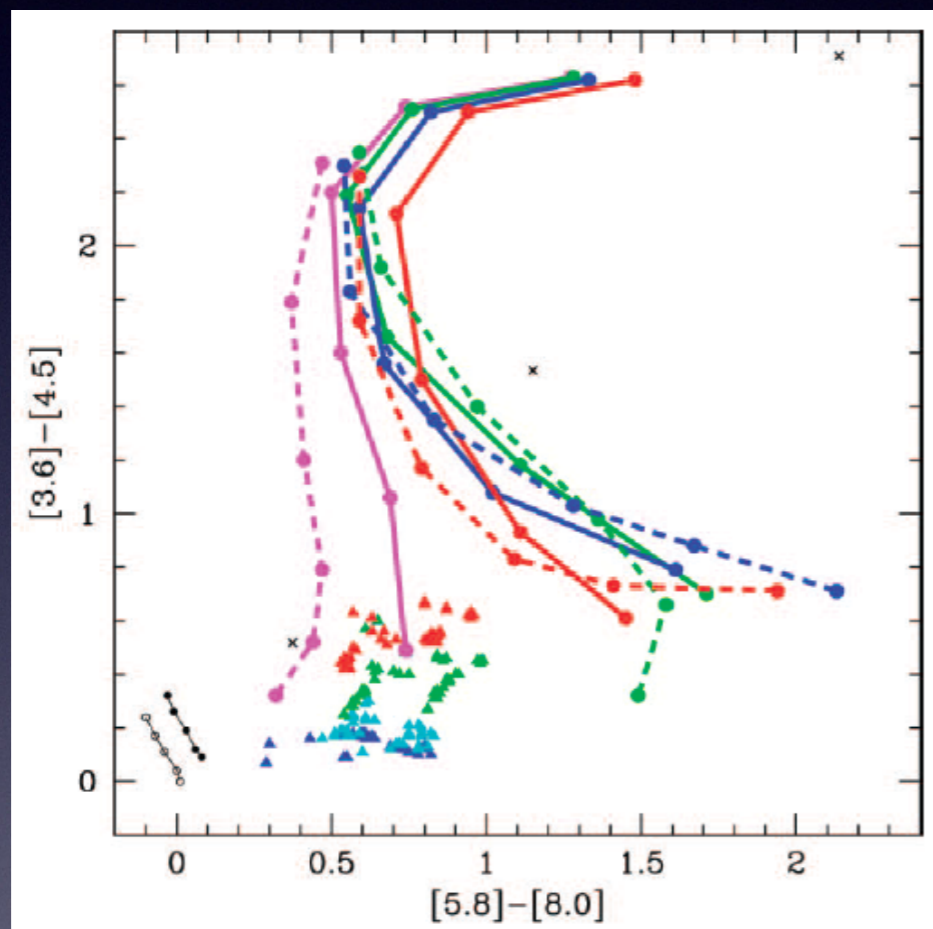
WISE as a YSO finder

- WISE is an excellent finding tool for Young Stellar Objects (YSOs)
- Dusty disks and envelopes around young stars are sensitively probed by mid-infrared photometry
- Dust in disks is at right characteristic temperature, plus large disk surface area produces large excess of emission above the stellar photospheric level

- Census of YSOs enables:
 - Estimate recent or current star formation rate
 - Disk fractions (hence lifetimes) and disk properties
 - Assess the structure and distribution of star formation

Spitzer

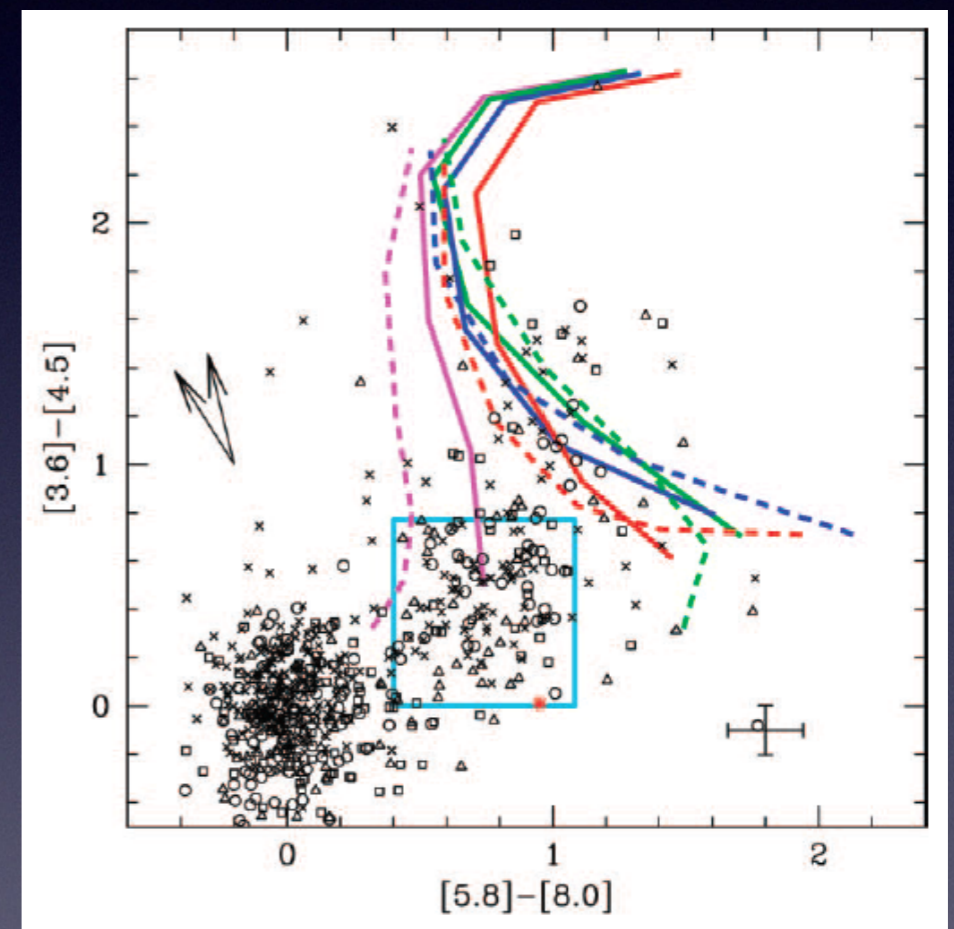
- Simple YSO models show stars, stars with disks and stars with disks and envelopes occupy distinct locations in mid-IR color space



Allen et al. (2004)

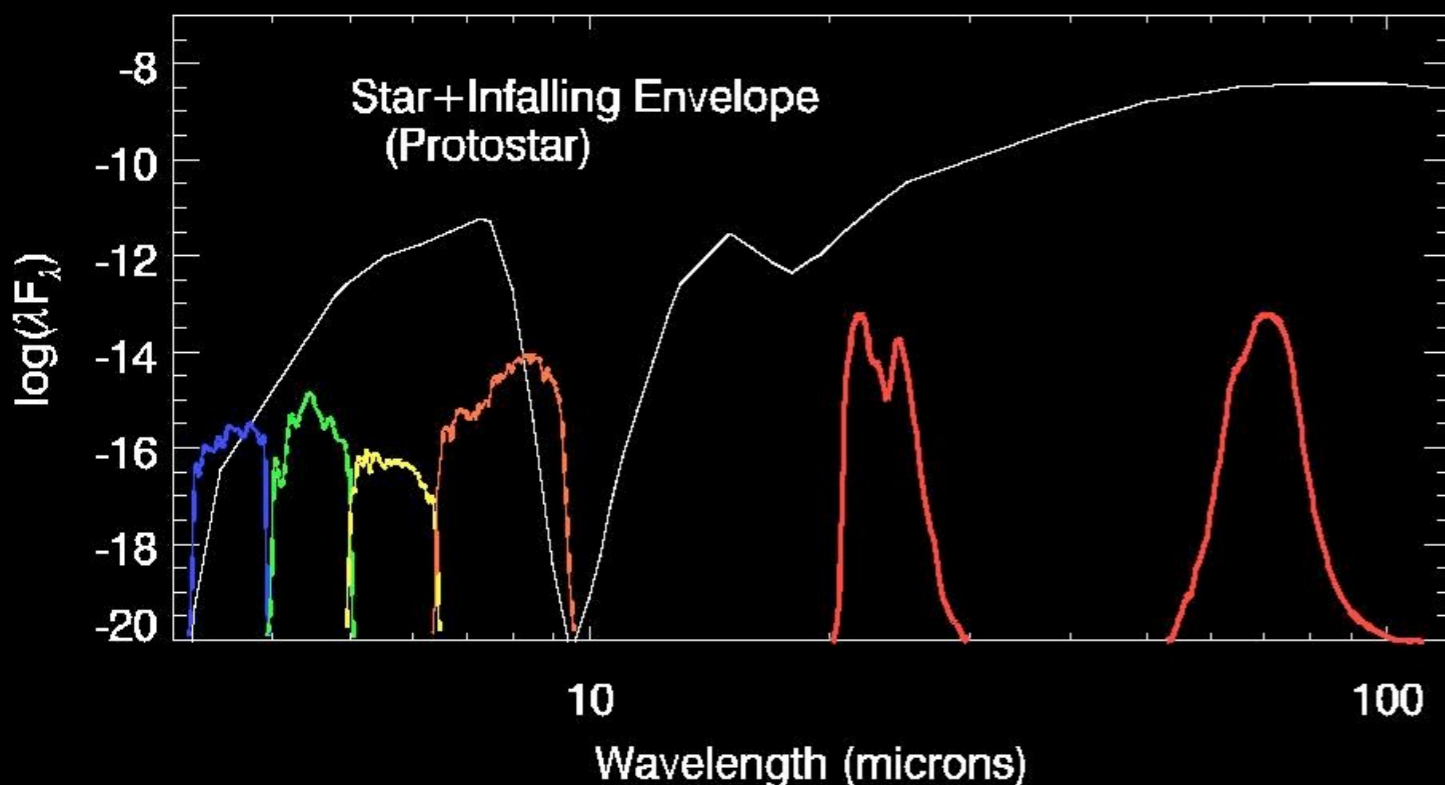
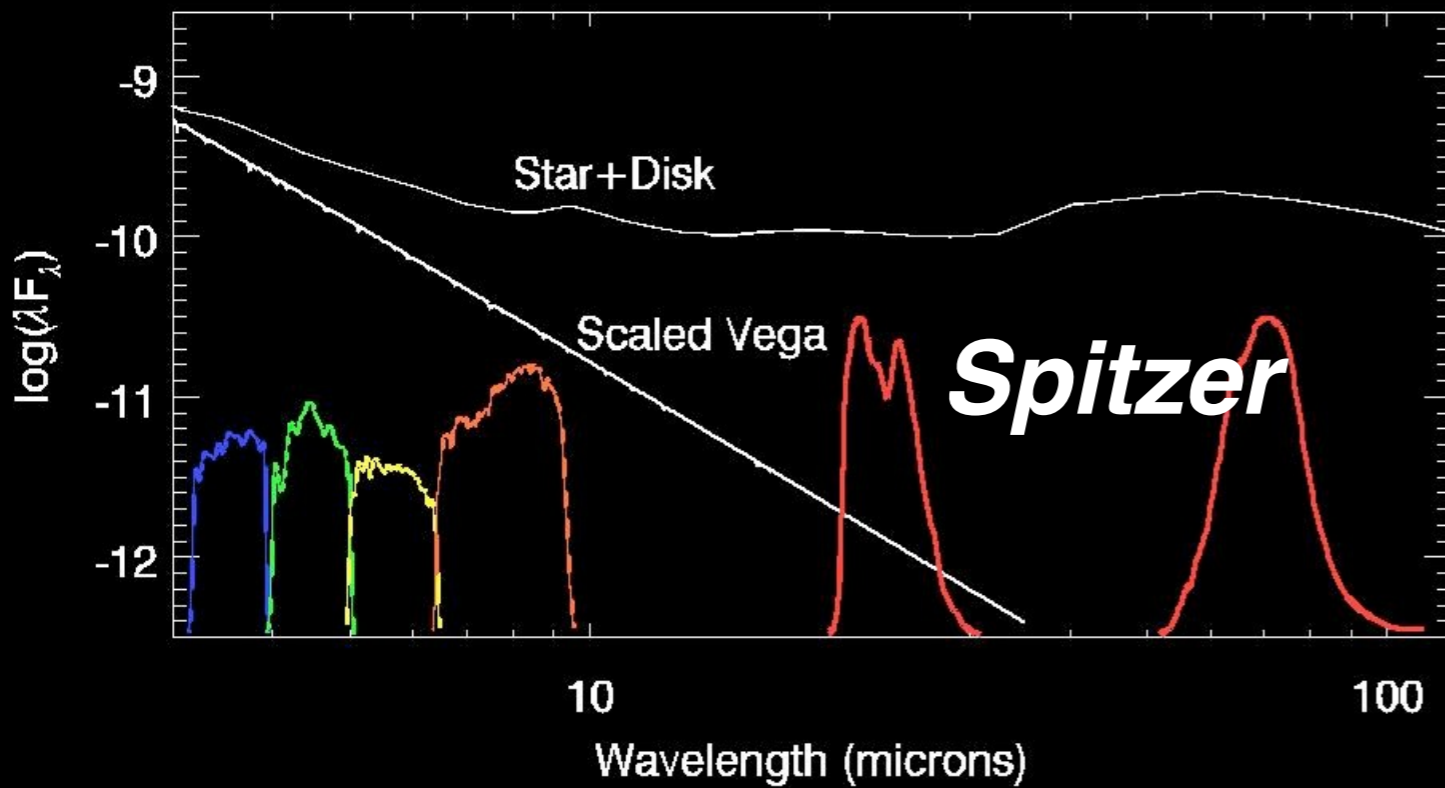
Disks - triangles, varying accretion rate, inclination, dust properties

Envelopes - filled points and lines, varying central source L , envelope density, centrifugal radius



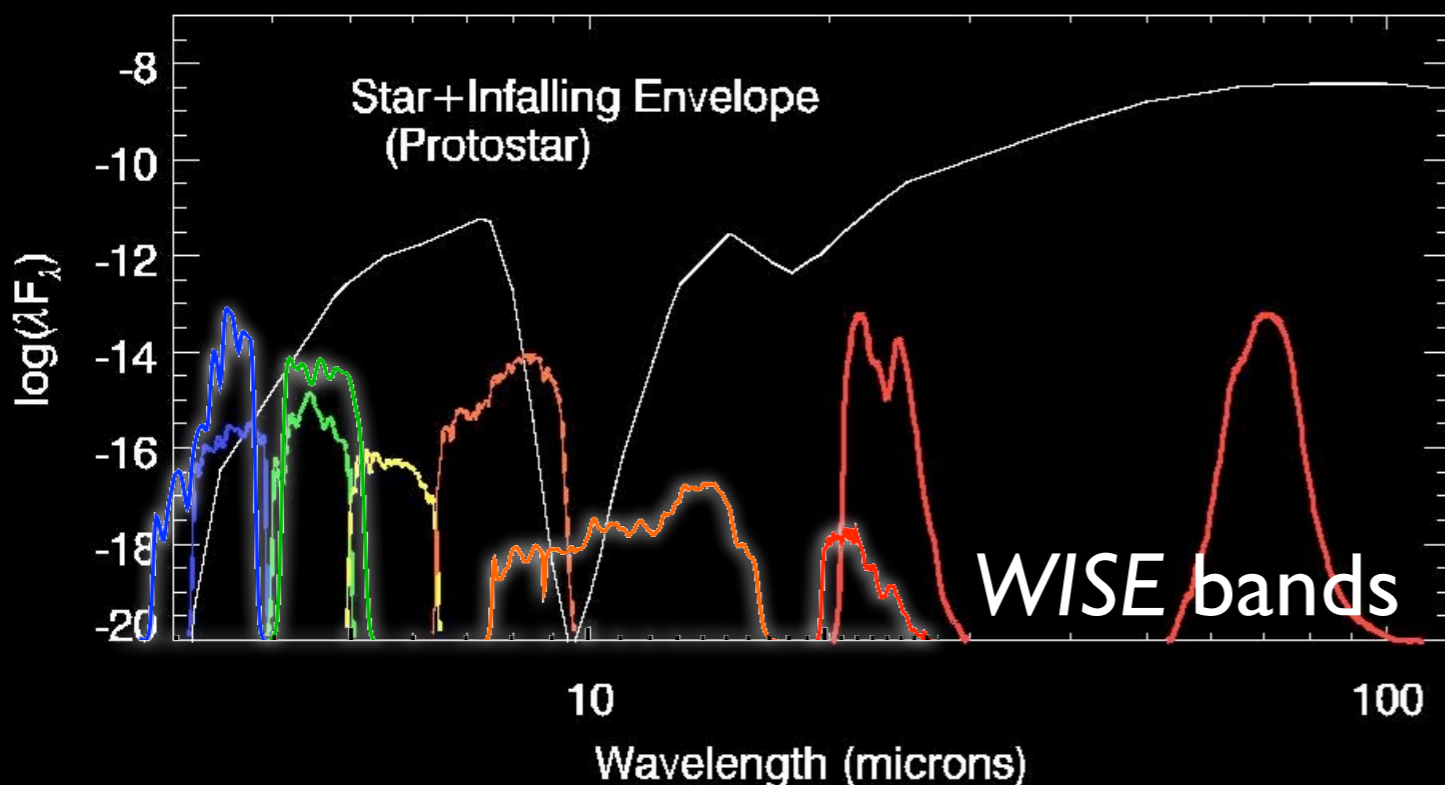
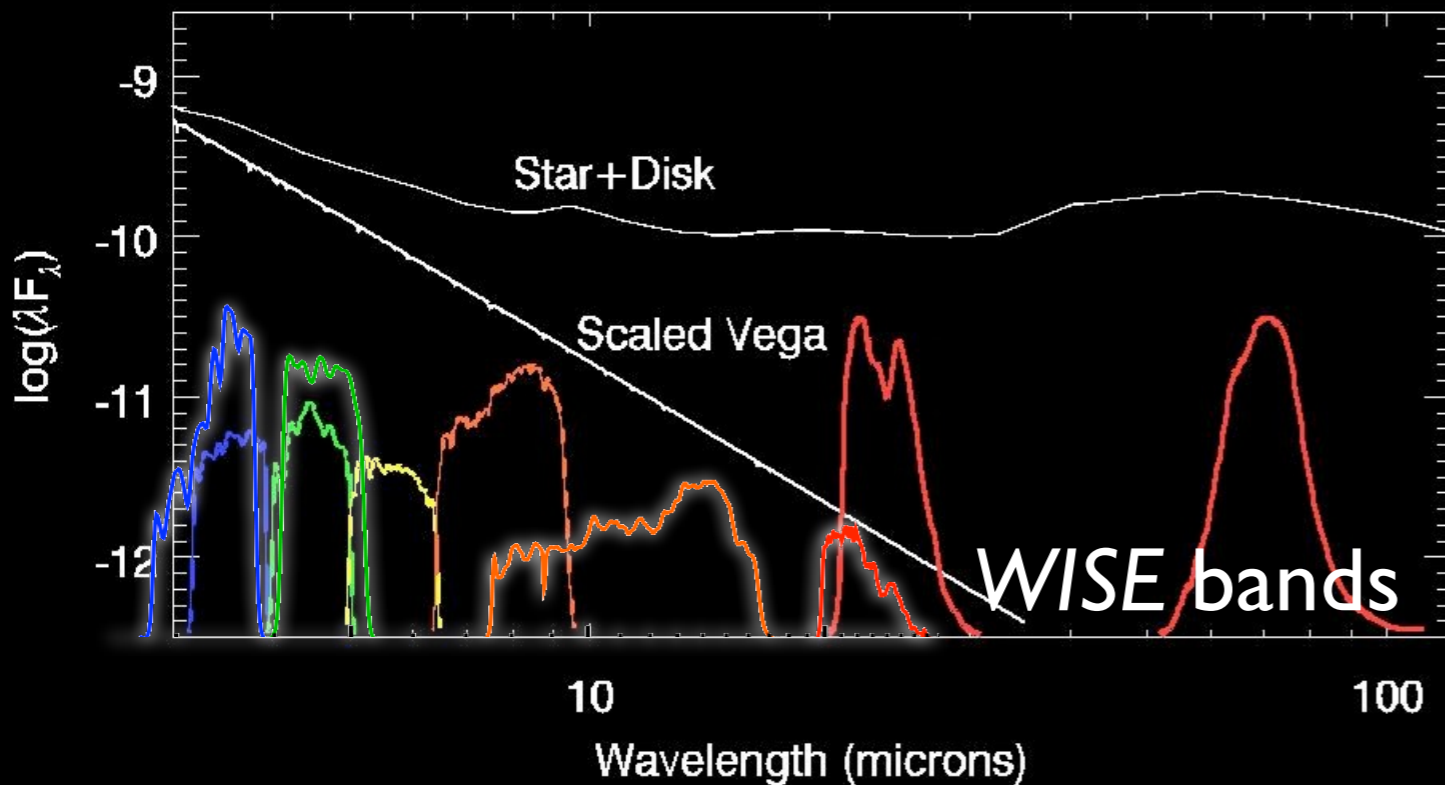
Black symbols - YSOs from nearby star forming regions

Spitzer



- Several color selection and classification schemes developed as a result, e.g. Cores 2 Disks (Evans et al. 2009), Gutermuth et al. (2008, 2009)
- Similarity with WISE bandpasses naturally led us to try the same thing

Spitzer



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WISE data challenges

Test case:

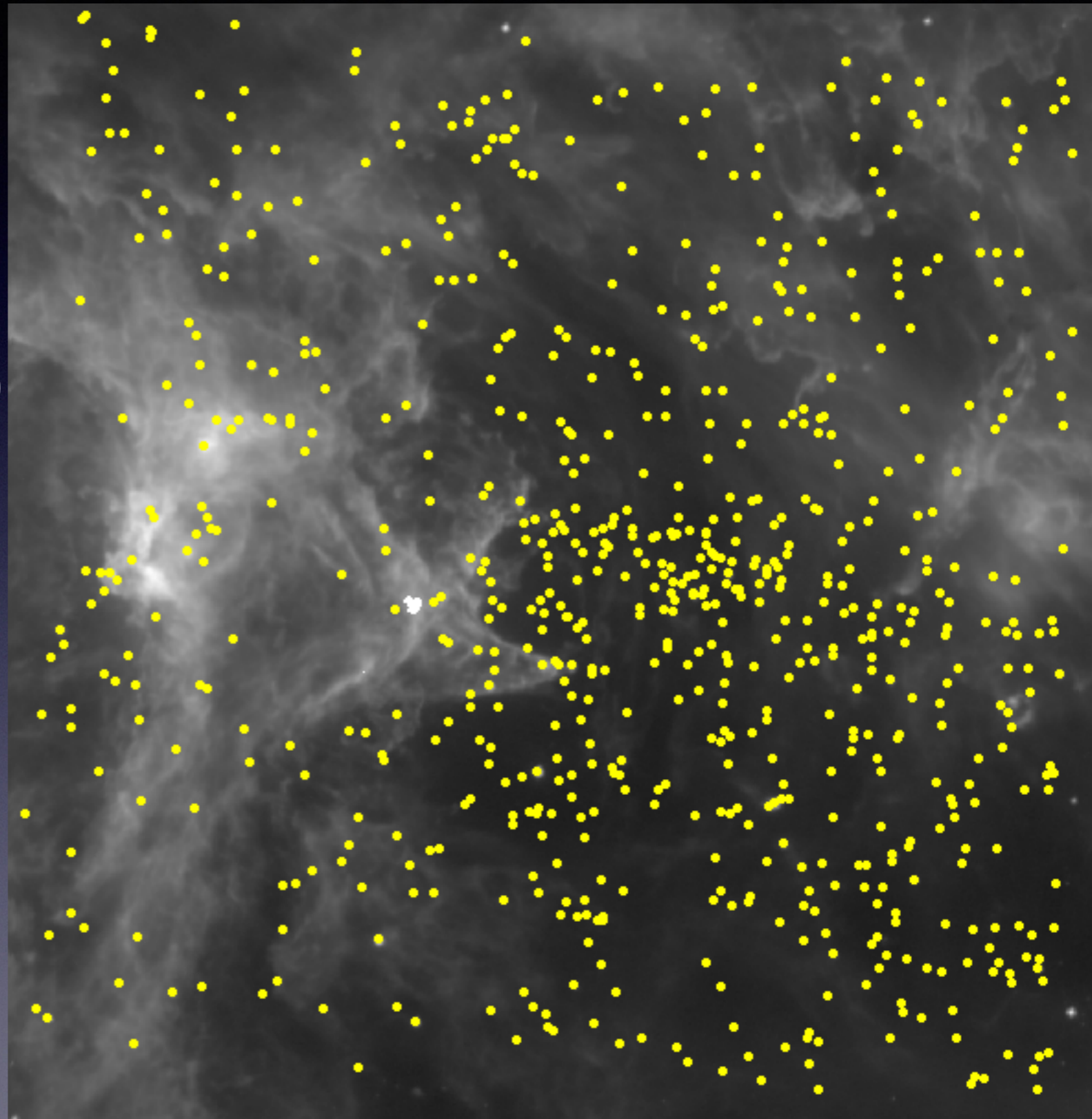
- W5 Massive SFR
- 12 μm greyscale (produced w/ icore)
- Find all visible point sources, guided by Spitzer 8 μm image of same field - **yellow points**
- **Red points** - AllWISE catalog entries w/ non-null `w3sigmpro`



WISE data challenges

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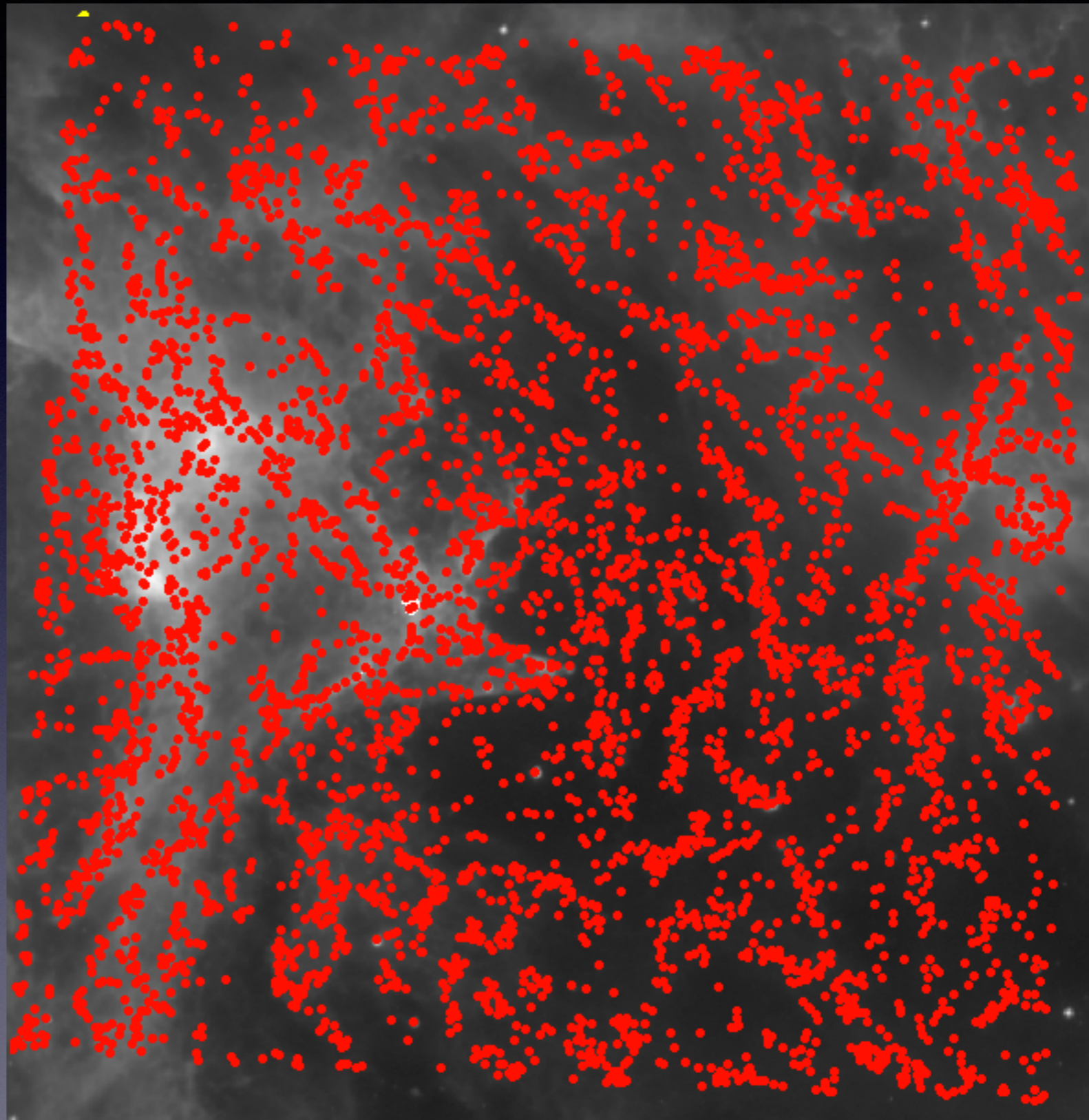
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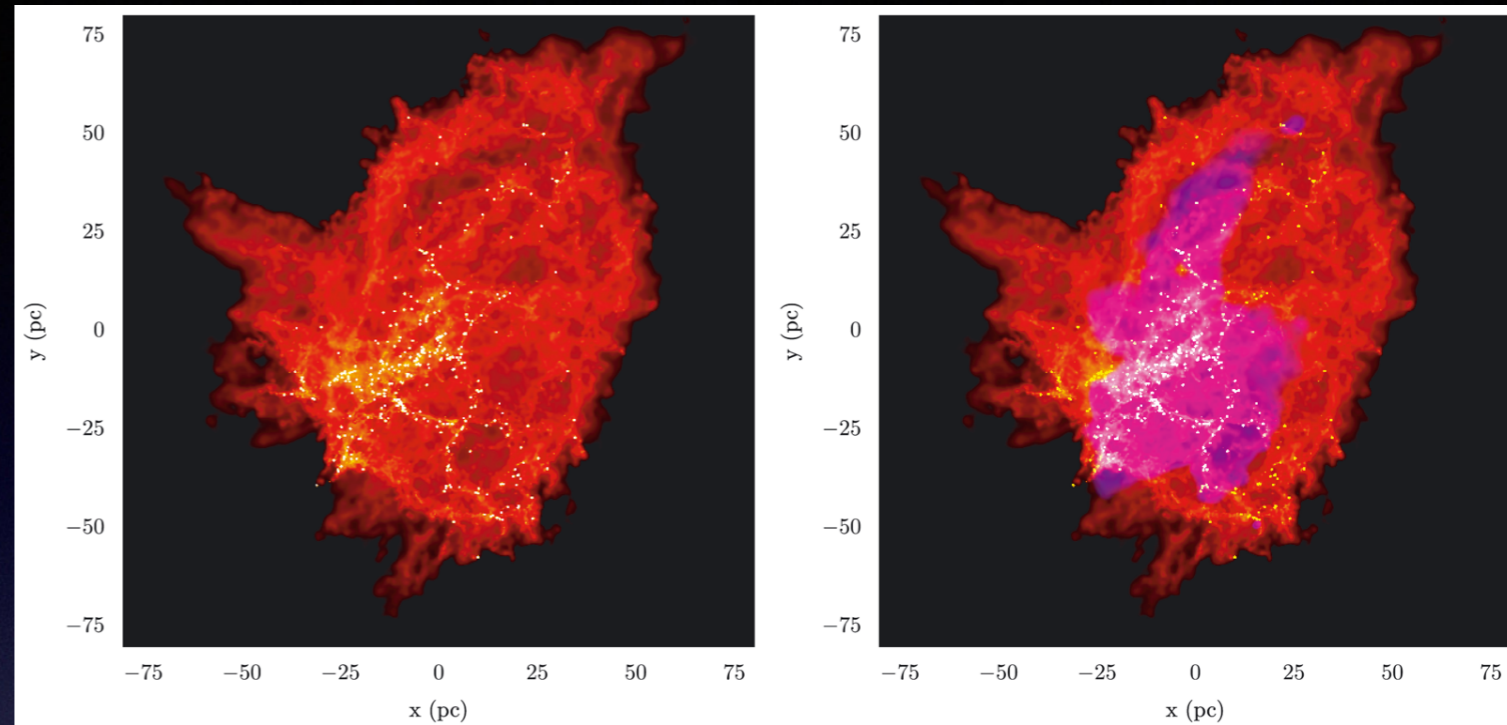
- Approach #1 - build our own mosaics and catalogs
- icore - assemble WISE mosaics
- PhotVis - aperture photometry software
- Calibrate with reference to existing pipeline products

Application: Triggered Star Formation

- Can the distribution of YSOs in massive star forming regions tell us about the mechanism of subsequent, secondary star formation?
 - Option 1: Radiatively driven implosion of pre-existing structure
 - Option 2: Collect and collapse of newly created density structures

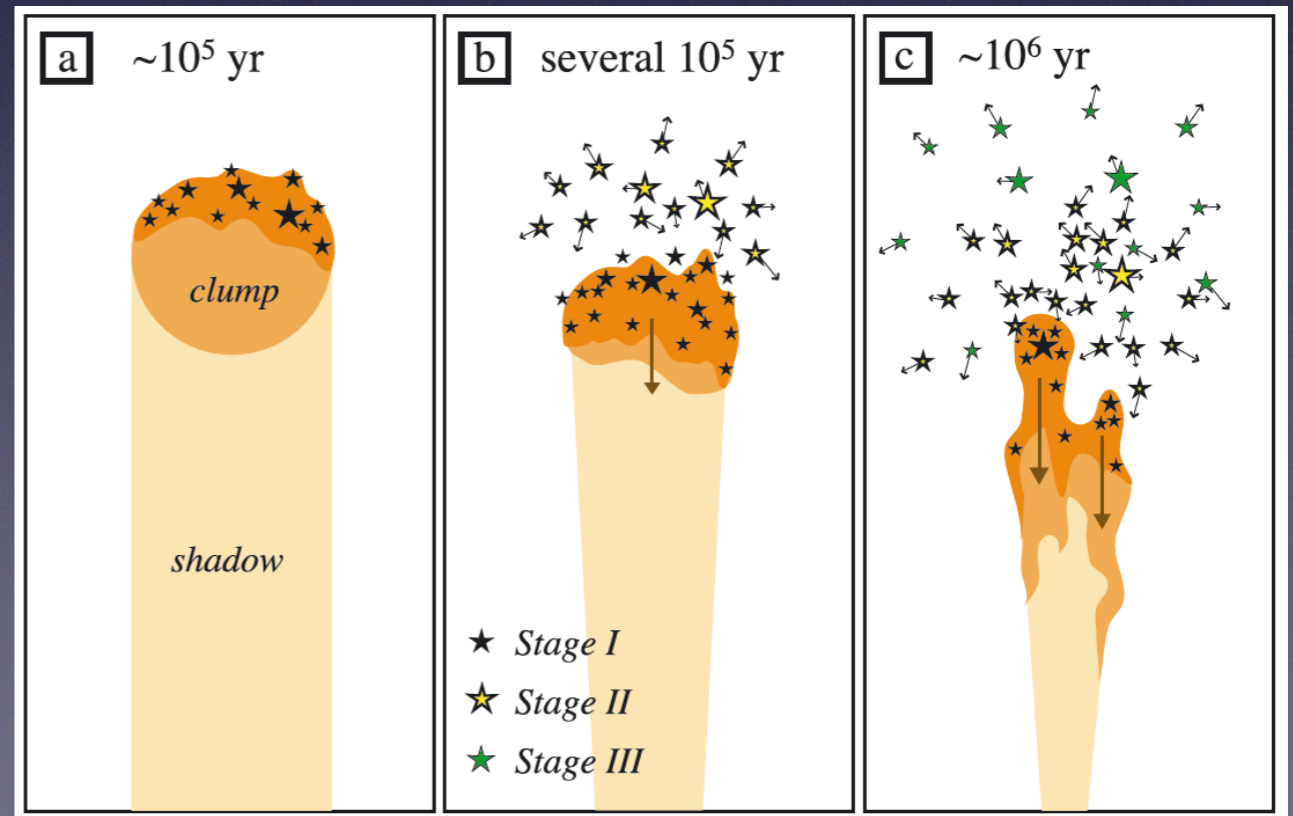
RDI

- Molecular cloud simulations with addition of massive stars suggest initial density substructure is robust to the formation of the HII region



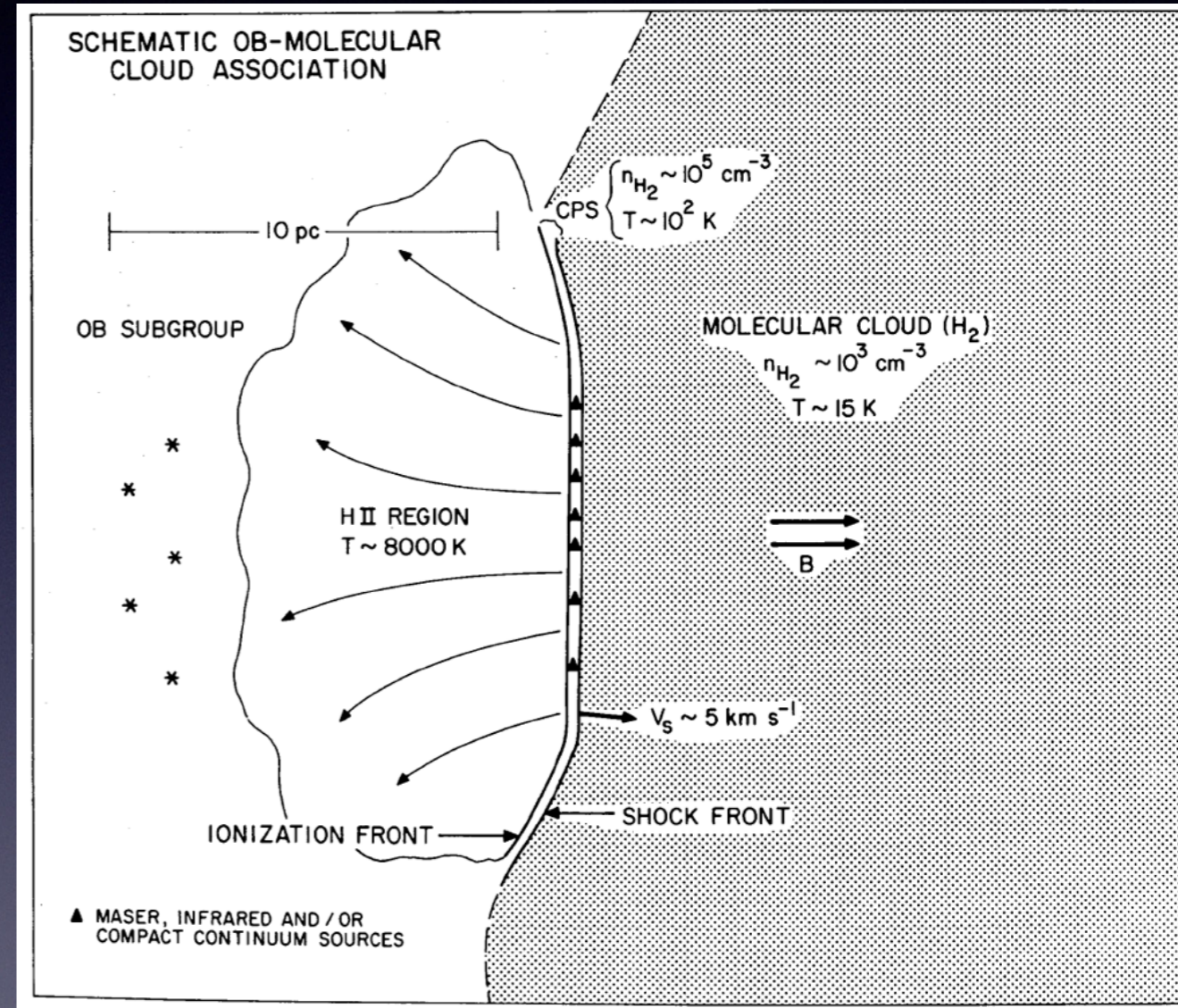
Molecular cloud evolution after 1.1 Myr,
Cloud Mass = $10^6 M_{\odot}$ (Dale & Bonnell 2011)

- Subsequent erosion and compression of clumps leads to new star formation



Collect and Collapse

- The expanding HII region creates an ionization front preceded by a shock front
- Neutral gas accumulates and at some point collapses to new star formation



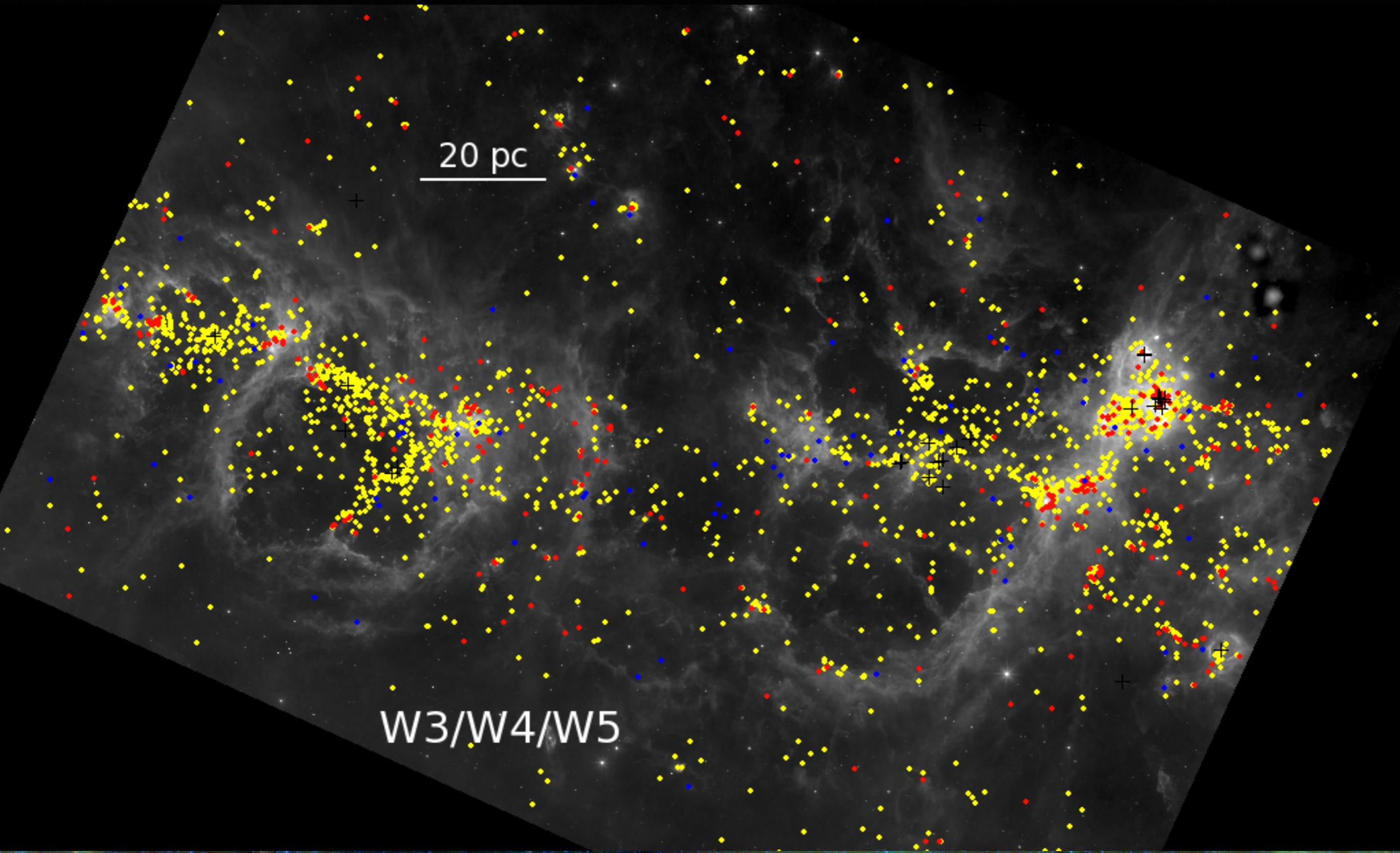
Elmegreen & Lada (1977)

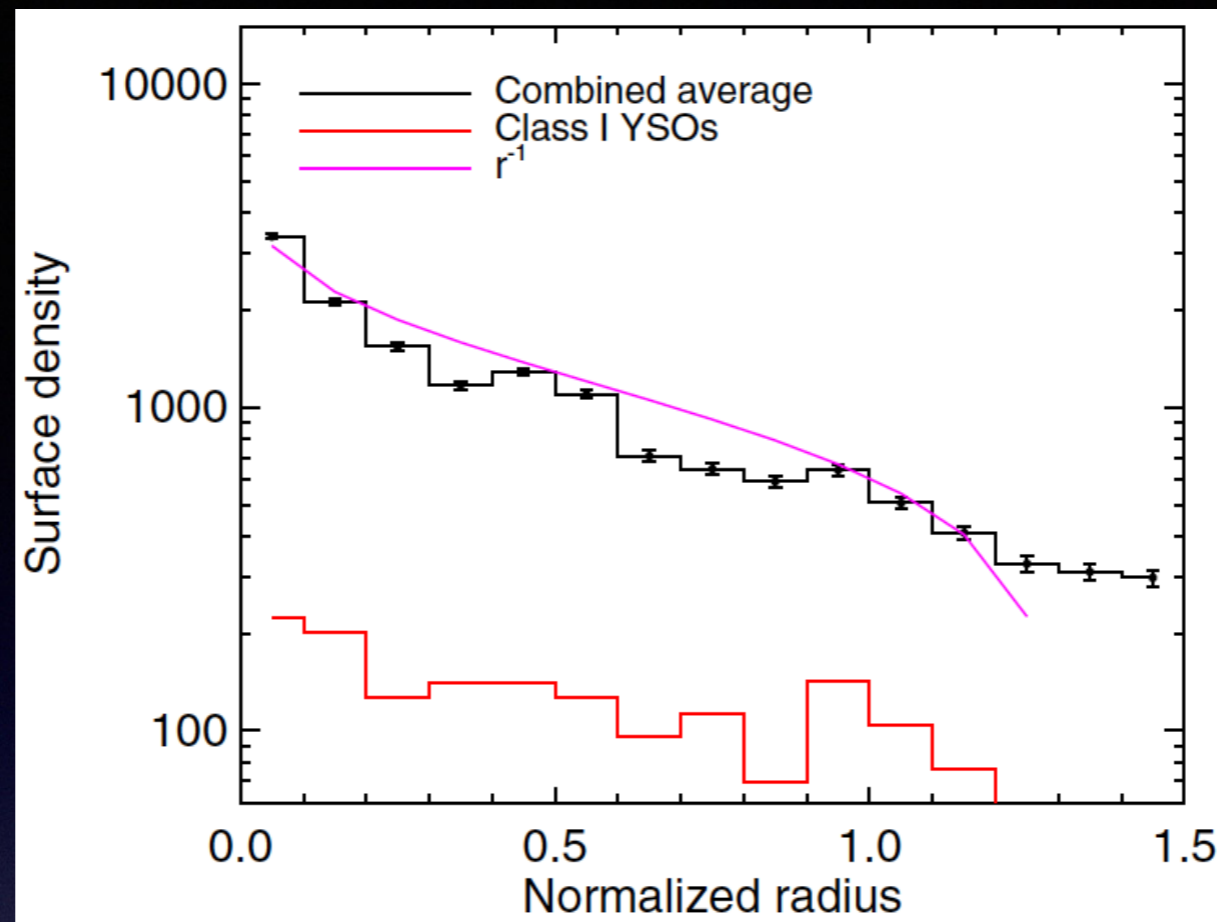
YSO distributions - 9 massive regions or complexes



Koenig et al. (2012), Color figure: D. Benford, R. Hurt

YSO distributions - 9 massive regions or complexes

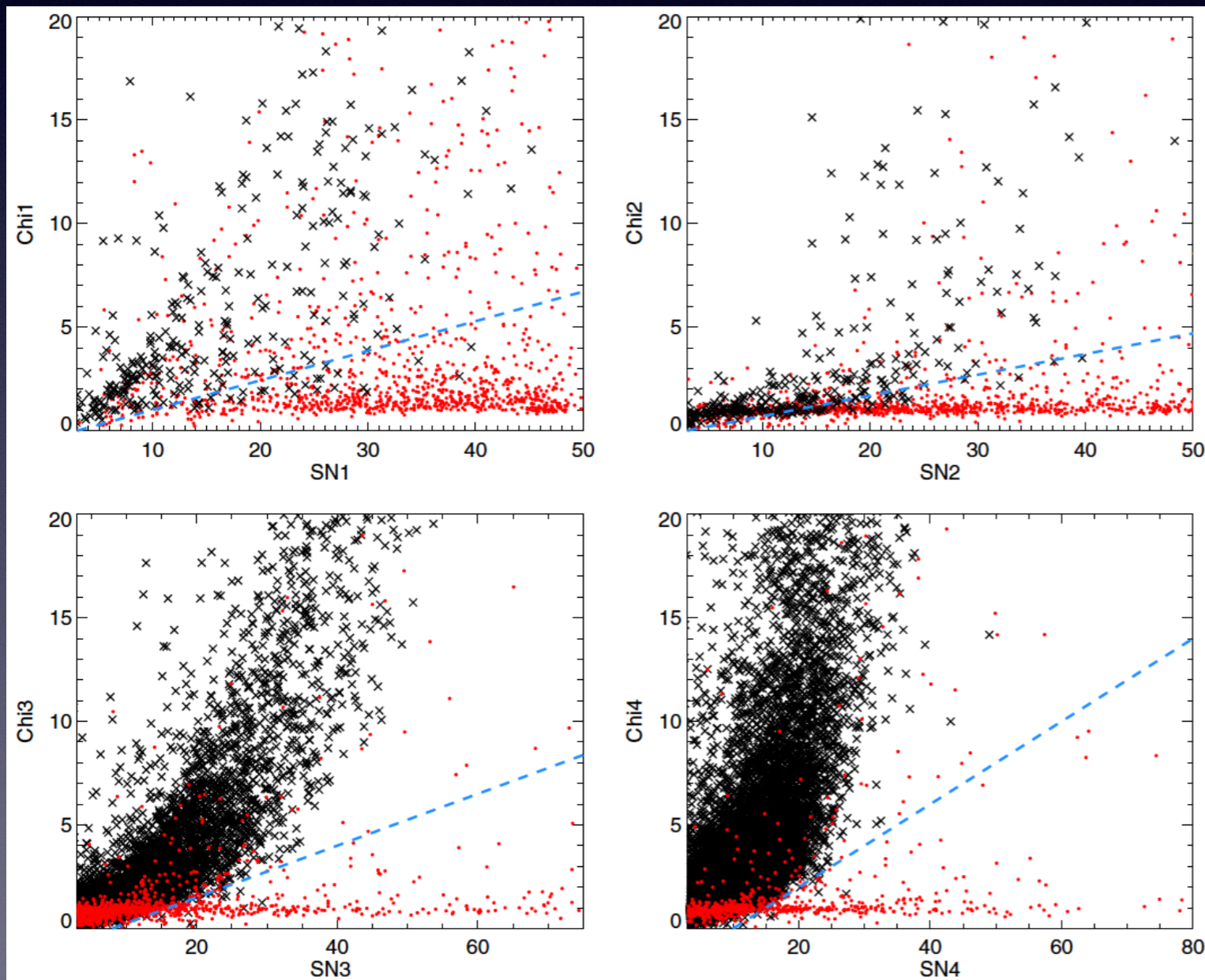




- Averaged 1D radial profiles of YSOs in these massive regions more consistent with star formation in pre-existing structure
- Collect and collapse not ruled out, but less important
- Behavior on super-bubble scales ($>100\text{pc}$ diameter) not addressed

- Approach #2 - develop photometric quality criteria to enable usage of public WISE catalogs
- Fully exploit WISE's all sky coverage
- Application: study the large scale distribution of star formation in the Galaxy

- Investigated several potential selection tools:
 - $w?nm/w?m$, $nb-na$, $w?mag$ vs. $w?mpro$, cc_flags , $w?snr$ and $w?rchi2$
 - Most powerful selection provided by $w?snr-w?rchi2$ diagram:



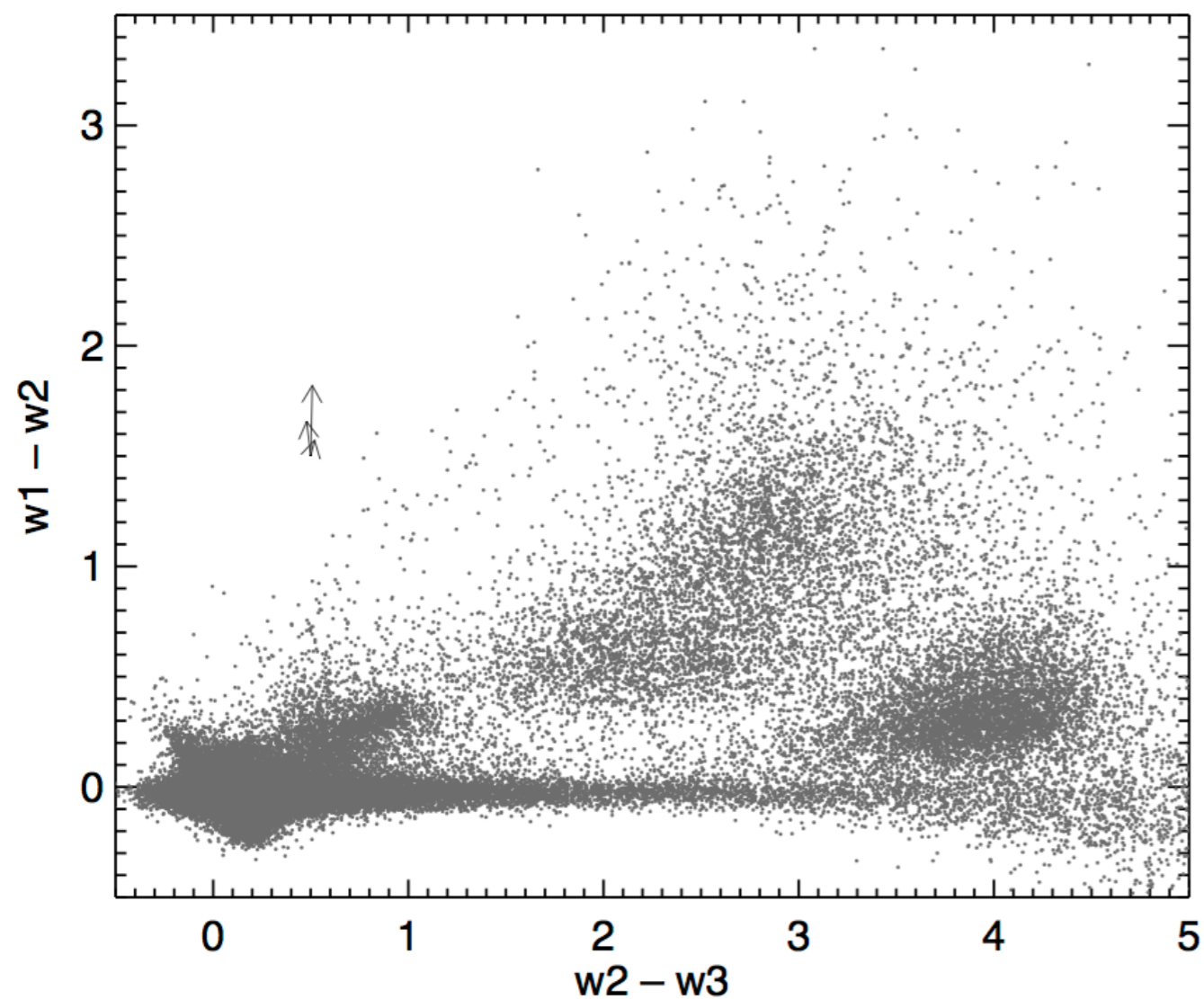
$w?snr-w?rchi2$ plots for IC 1848 test field

All points are an entry in the AllWISE catalog w/ non-null $w?sigmpro$

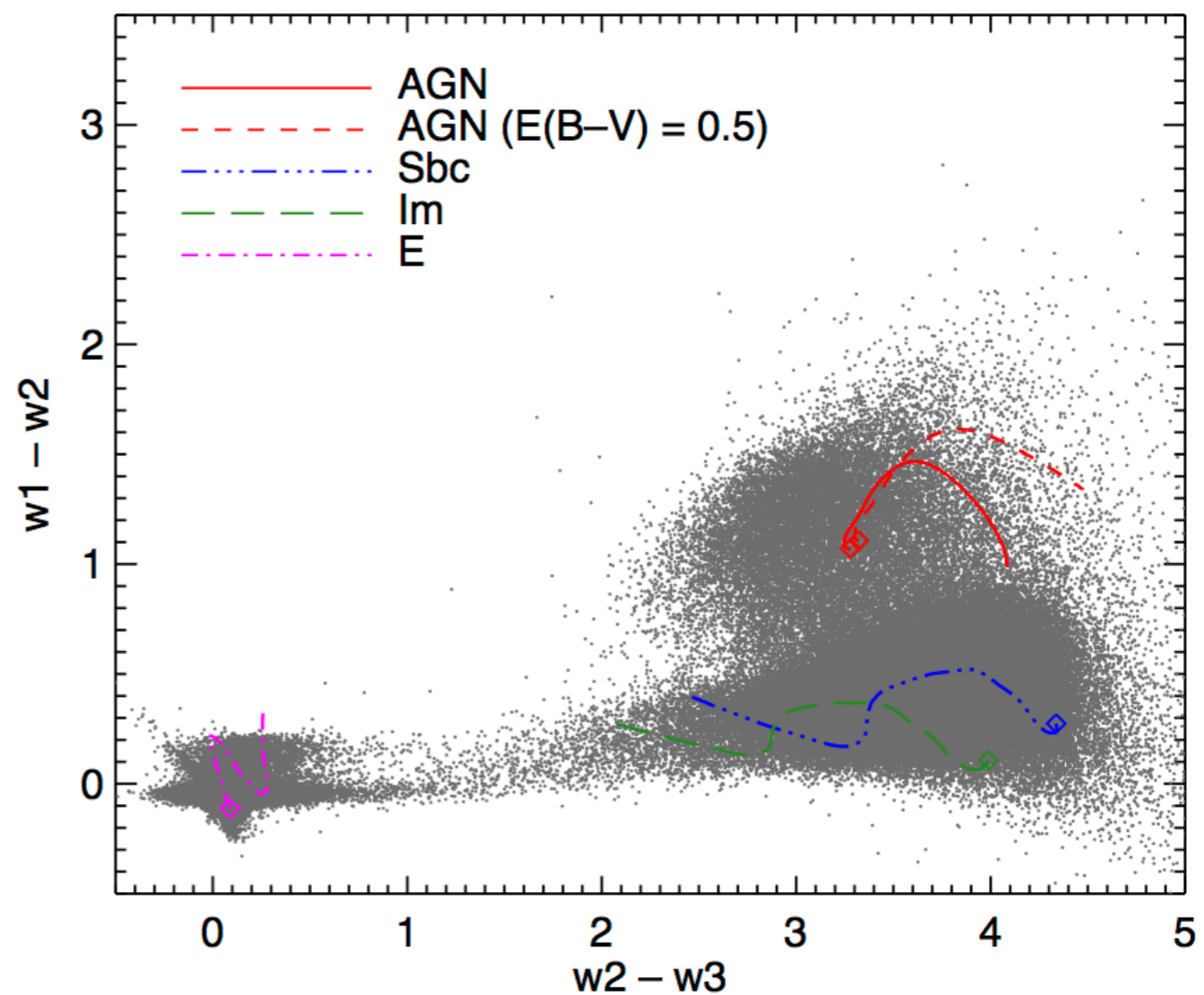
Red points - point source apparent in image

Black cross points - no visible point source

The 'cleaned' AllWISE catalog:

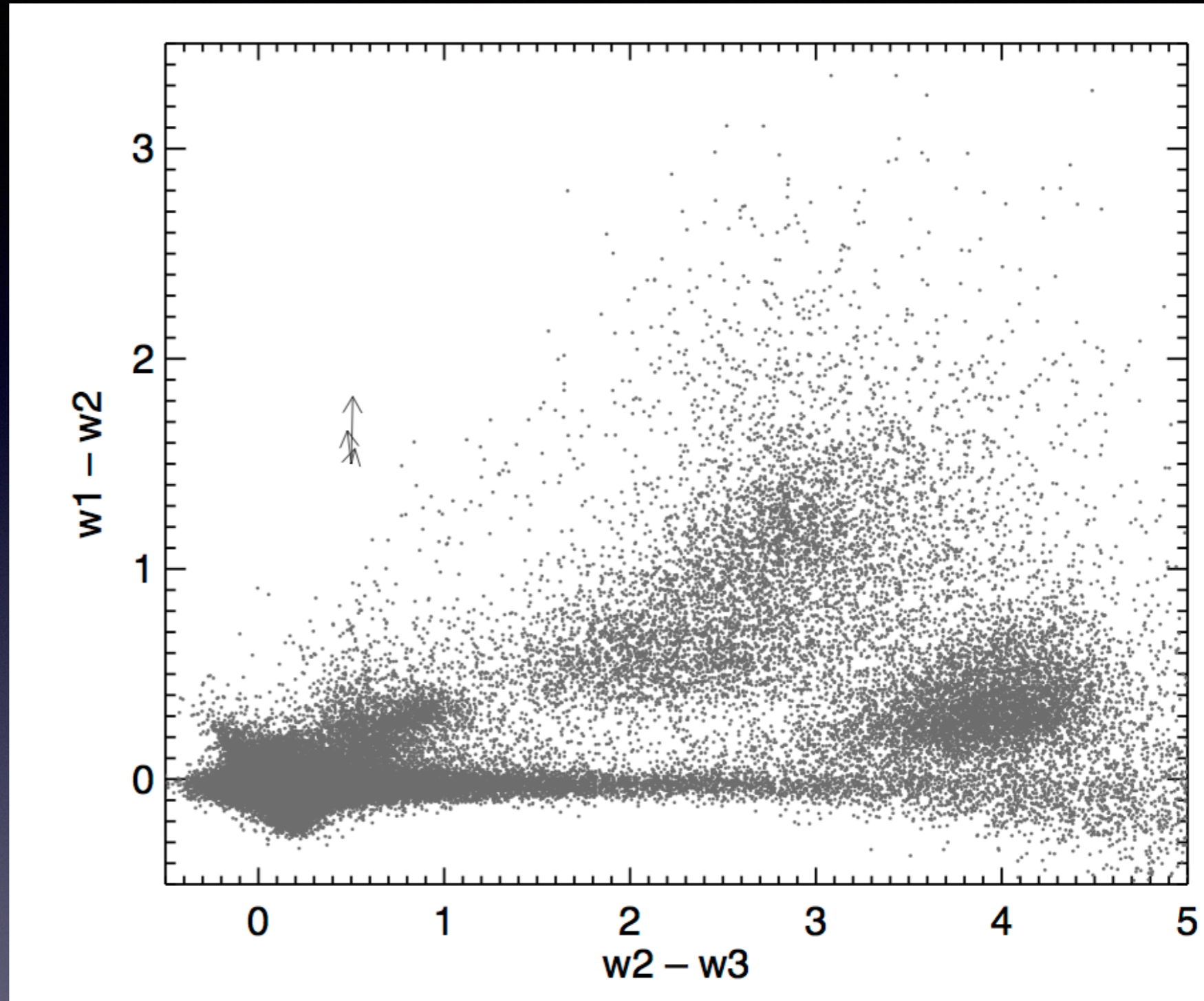


Galactic Plane field
 $\sim 500 \text{ deg}^2$



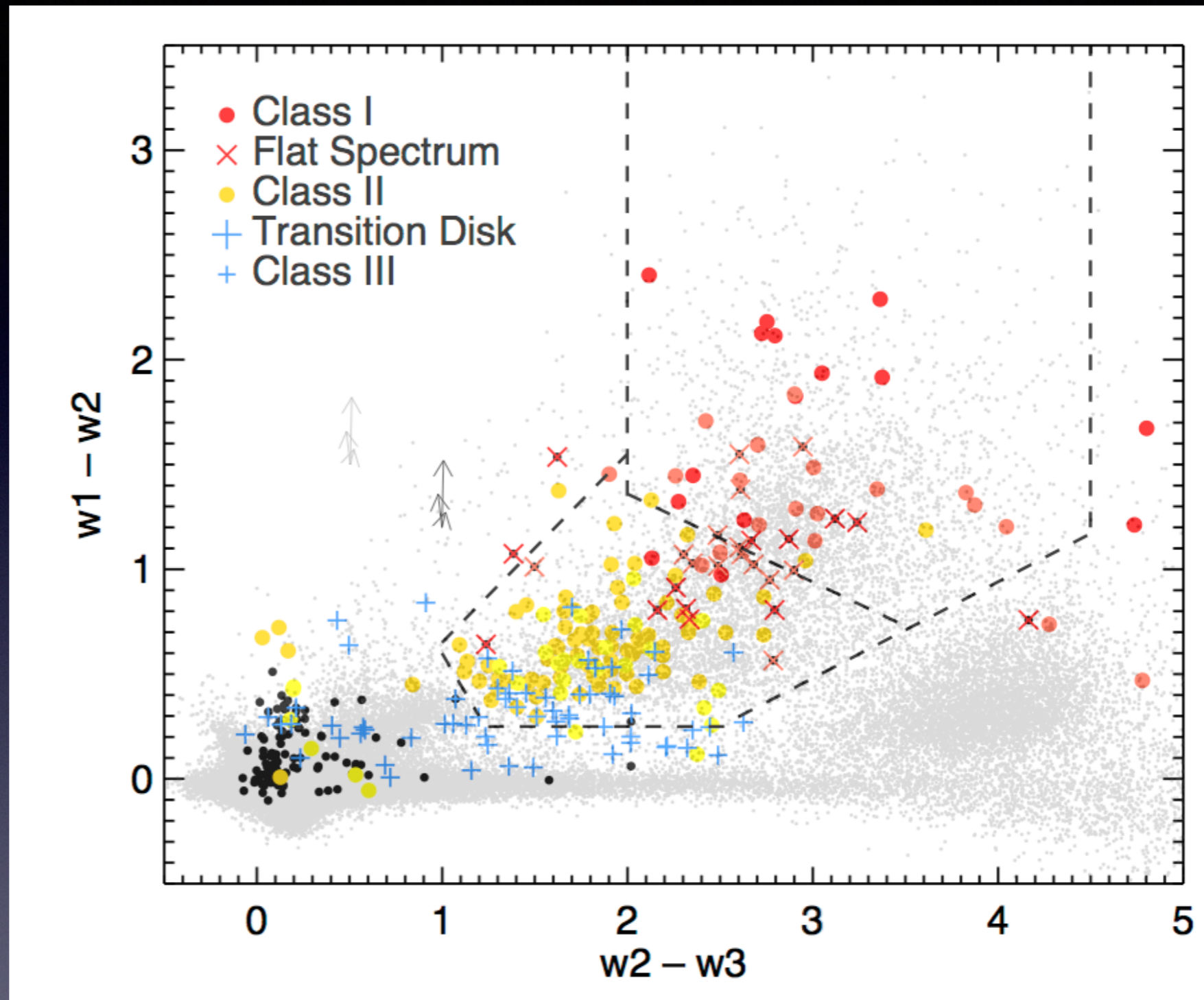
Galactic Pole field
(tracks from Roberto Assef)

- Use literature samples of source types to build YSO selection scheme
- Successive steps use magnitude and color cuts to avoid non-YSOs



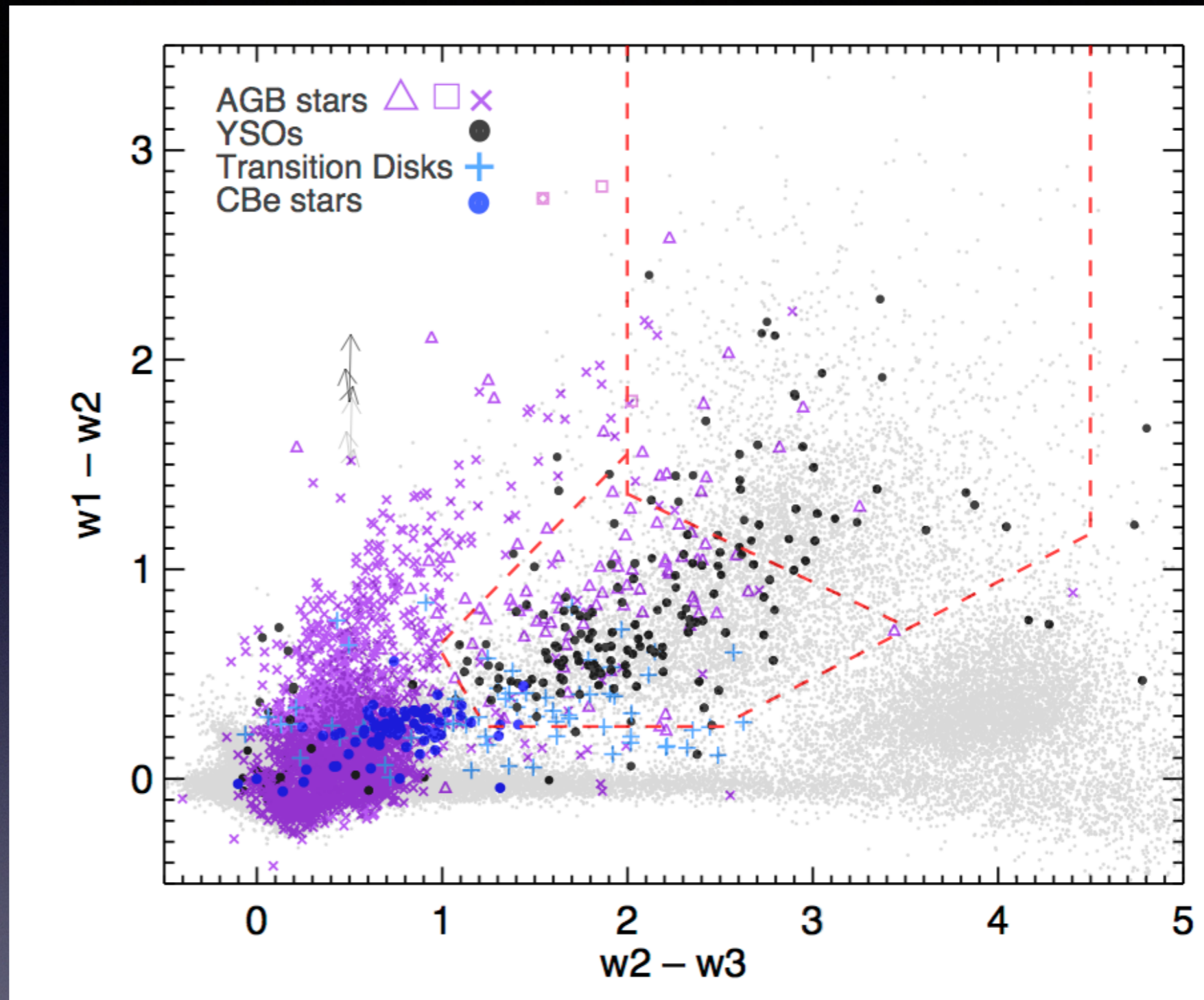
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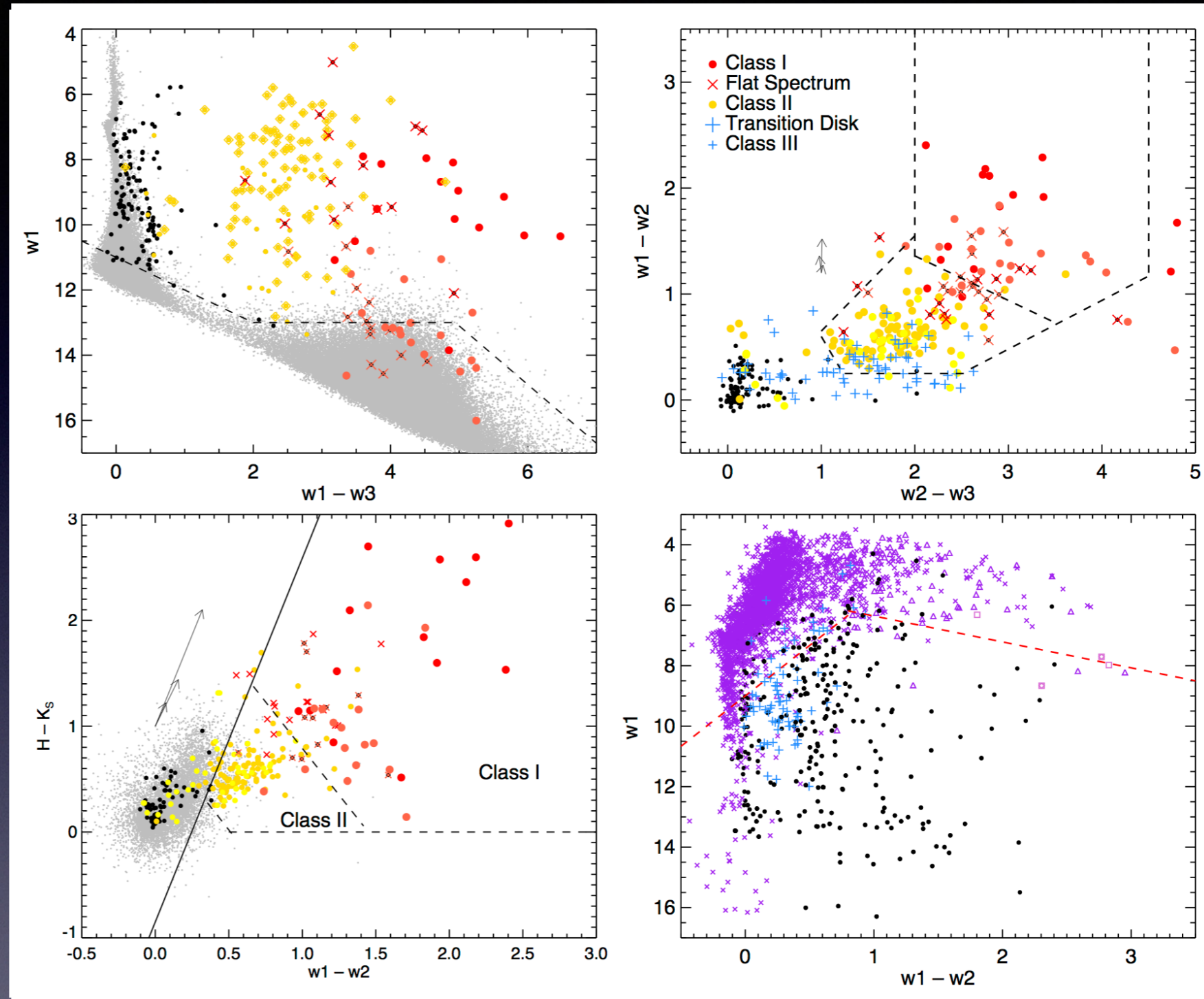
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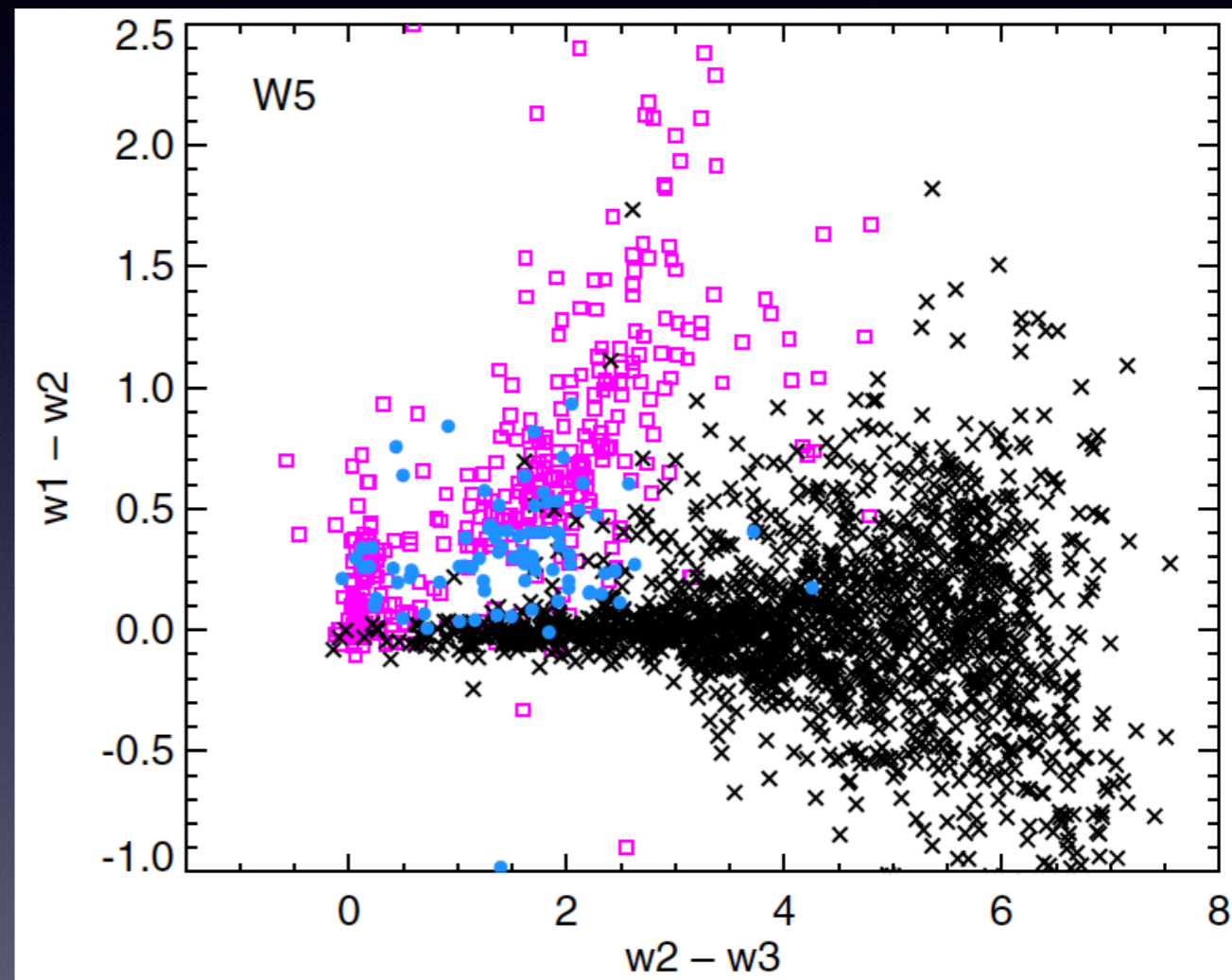
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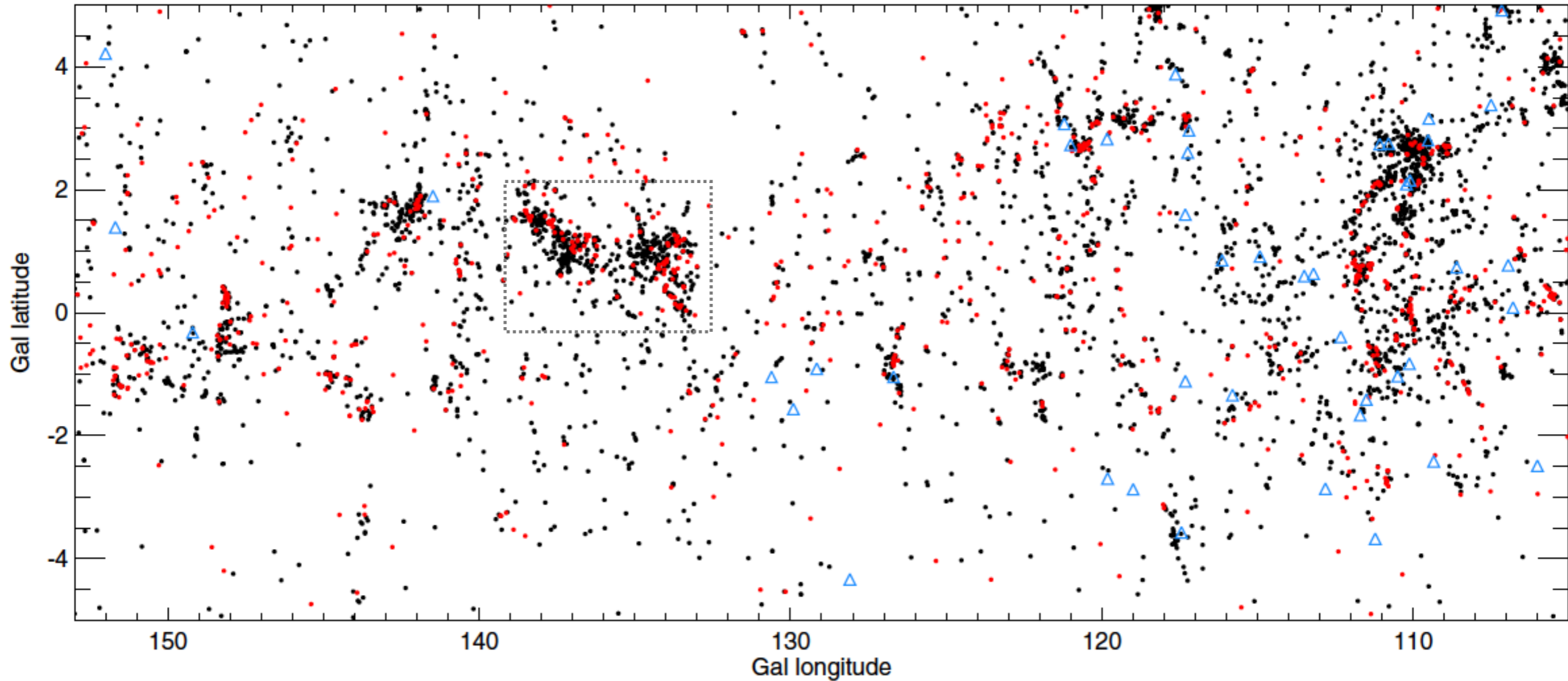
- Retrieve YSOs at low signal to noise because YSOs are less red than spurious detections



Taurus YSOs from Spitzer (Rebull et al. 2010)

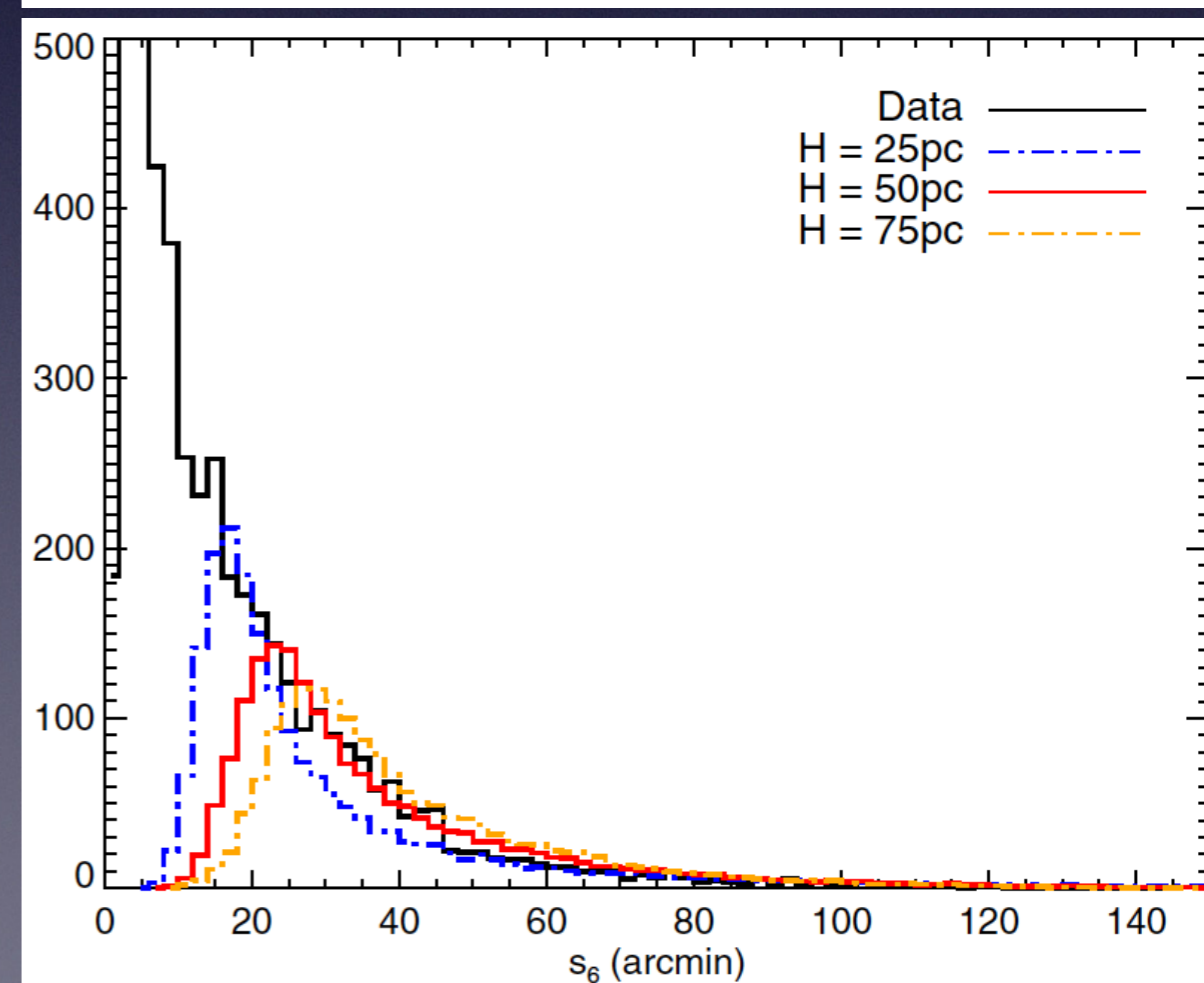
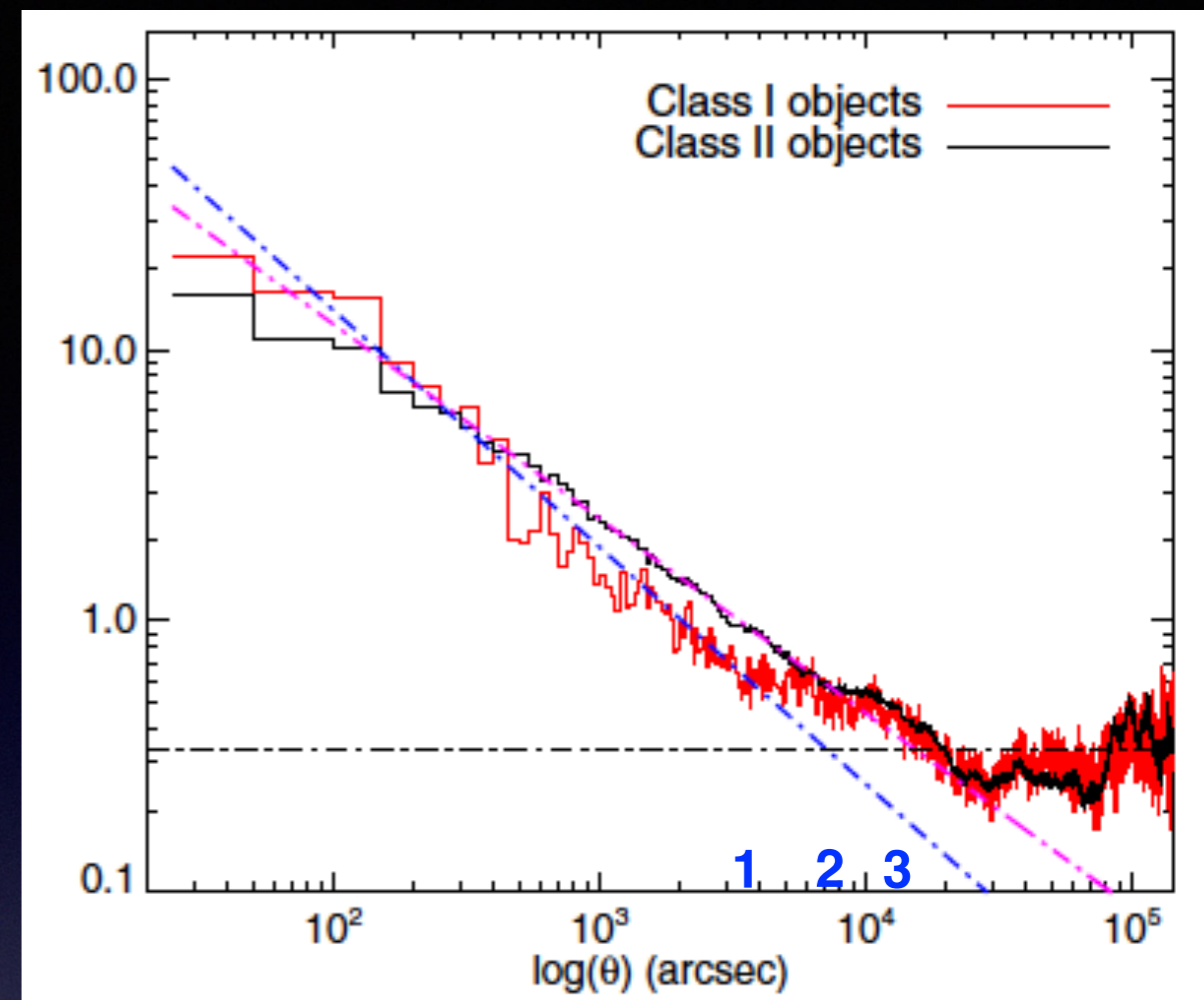
Transition disks from Andrews et al. (2011),
Cieza et al. (2012)

Black crosses - spurious w3 detections in IC 1848



- Apply scheme to section of Outer Galaxy
- What is the relative contribution of any non-clustered population?

- Remove residual non-YSOs in Monte Carlo fashion using polar field galaxies and Wainscoat et al. (1992) Galactic populations model
- Build two-point correlation function for youngest (Class I) and older (Class II) YSOs - appear largely fractal
- Measure space density distribution using nearest neighbor distances
- At most 25% of the low density tail could be explained by a smooth, scale-height population
- Note! Unresolved clusters at large distance (Izumi) push the unclustered fraction lower



Future

- Star formation rate to gas density estimates
- BOSS and other spectral follow-up
- Disk-detectives partnership to attempt all-sky YSO extraction and verification
- GAIA distances and proper motions - 3D distribution and disk fraction
- LSST and PanSTARRs variability

